Spatial Dependence and Cluster Persistence in Drinking-Water Quality Risk: Municipal Evidence from the Department of Santander, Colombia, 2007–2020

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Abstract

Drinking-water quality risk in Colombia is monitored through a single municipal indicator, the Water Quality Risk Index (IRCA), yet its spatial structure has not been examined. This study analyzes the 87 municipalities of the department of Santander between 2007 and 2020 (1202 municipality-year observations from SIVICAP/INS) using exploratory spatial data analysis. Global Moran's I is estimated annually and by period, together with local indicators of spatial association (LISA), the Getis-Ord Gi* statistic, and a cluster-persistence test based on a binomial contrast with false discovery rate correction. Spatial dependence was positive and significant before 2014 ($I = 0.113$; $p = 0.036$) and became undetectable afterward ($I = 0.046$; $p = 0.183$); the share of IRCA variance attributable to spatial structure fell from 5.0% to 1.0%. The change in IRCA showed no detectable spatial clustering ($I = 0.044$; $p = 0.198$), suggesting, though not confirming, that the improvement did not spread through geographic contiguity. Cluster persistence reveals an asymmetry: eight municipalities maintain statistically significant low-risk cluster status after multiple-testing correction, led by Páramo (9 of 14 years) and San Gil (8 of 14), while no high-risk cluster survives that correction. The mean distance among the ten lowest-risk municipalities (≈60 km) remains below the departmental average (82.1 km) in both periods, whereas that among the ten highest-risk municipalities increases from 70.6 to 90.2 km. Finally, 2020 shows significant negative autocorrelation ($I = -0.114$; $p = 0.040$), coinciding with an increase in municipalities reporting an IRCA of zero (31 of 87, versus 1 in 2018), which suggests a disruption in the surveillance system rather than an actual change in water quality. Water safety consolidates territorially, whereas high risk does not form stable spatial structures.